HiEx Foam

The Ultimate Fire Fighter Goes Where No Foam Has Gone Before

NRL's Navy Technology Center for Safety and Survivability is running full-scale fire tests on high expansion (HiEx) foam for shipboard firefighting to protect large volume mission-critical spaces. HiEx foam is 3D capable; that is, it expands to fill up the volume of flammable spaces in minutes, flowing around obstructions that previously mandated manual firefighting in order to completely extinguish fires. And it does so with less liquid solution, meaning less water damage and less resulting clean-up. NRL researchers solved the critical problem of traditional HiEx systems requiring fresh air, a rare commodity in shipboard spaces that are already aflame, by focusing on the use of fire compartment air. Because of NRL's research, HiEx foam is a strong candidate for inclusion into future (and safer) ship design.

High Expansion Foam for Protecting Large Volume Mission Critical Shipboard Spaces

J.P. Farley and F.W. Williams
Chemistry Division

NRL's Navy Technology Center for Safety and Survivability recently initiated a full-scale fire test series to demonstrate the efficacy of high expansion foam for protecting large volume shipboard spaces. High expansion foam was pursued because of its inherent ability to travel around obstructions, fill the volume in minutes, and provide a three-dimensional firefighting capability that would not depend on a manual firefighting attack to complete final extinguishment. In addition, it can accomplish all this by using only a small quantity of liquid solution, which results in reduced water damage and minimal clean-up after its use. The demonstrated success of this NRL fire test series has helped to generate considerable interest within the Navy's ship design community for incorporating high expansion foam systems into future surface ship designs.

INTRODUCTION

Large volume shipboard spaces can include multiple Class A (combustible solids) and Class B (flammable liquids) fire threats. Prior testing conducted onboard the NRL full-scale fire test ship, ex-USS *Shadwell*, has identified the limitations in protecting these large-volume spaces using aqueous film-forming foam (AFFF) sprinklers designed only to combat Class B two-dimensional pool fires.[1] The consequence of these noted limitations necessitates a manual attack when tightly stacked Class A materials or three-dimensional Class B running fuel fires are present. This requisite manual attack also introduces additional hardships when considering the degree of clutter and heavy smoke conditions that will be present, which adversely affects firefighting performance and personnel safety.

To address this, NRL recognized the tremendous capabilities of high expansion foam and developed an experimental fire test protocol to examine the possibility of incorporating it into a ship's firefighting system design. NRL further recognized that employing a traditional high expansion foam generator would impact shipboard applicability since it requires a fresh air supply (outside air) and an internal fan for suitable foam generation. For fixed high expansion foam systems aboard future ships, it would be advantageous, from a point of view of installation and cost, to have foam generators that do not require external duct work or moving parts, and simply use the fire compartment air (inside air) to generate the high expansion foam. This concept would also allow application well within the confines of the ship where immediate access to fresh air sources may be problematic. Historically, the use of inside air (i.e., hot air contaminated with combustion products) has presented a challenge.[2] Therefore, due to the potential economies that could be realized, NRL focused this experimental study to assess the efficacy of a new type of high expansion foam generator that has been specifically designed to work with inside air.

FOAM GENERATOR TECHNOLOGY

A manually activated, total flooding, high expansion foam system was selected for this experimental study. Manufactured by Svenska Skum AB, Kungalv, Sweden, it is called HotFoam. The system consists of a uniformly spaced overhead grid of small, unconventional generators (Fig. 1). Air is entrained by a spray nozzle within the generator to make the foam, rather than by a fan drawing outside air. The foam concentrate used was Meteor P+ synthetic foam concentrate, designed to be proportioned at 2 percent. The HotFoam Meteor P+ concentrate has been formulated to be suitable for use with fresh, sea, or brackish water and is environmentally acceptable.

FIRE TEST PROTOCOL

The full-scale fire tests were conducted onboard the NRL fire test ship, ex-USS *Shadwell*, located in Mobile, Alabama, in the Well Deck fire test area (Fig. 2). The dimensions of this area were 21.3 m (70 ft) long, by 13.4 m (44 ft) wide, with an 8.5 m (28 ft) high overhead. The total deck area was 285 m^2 (3080 ft^2).

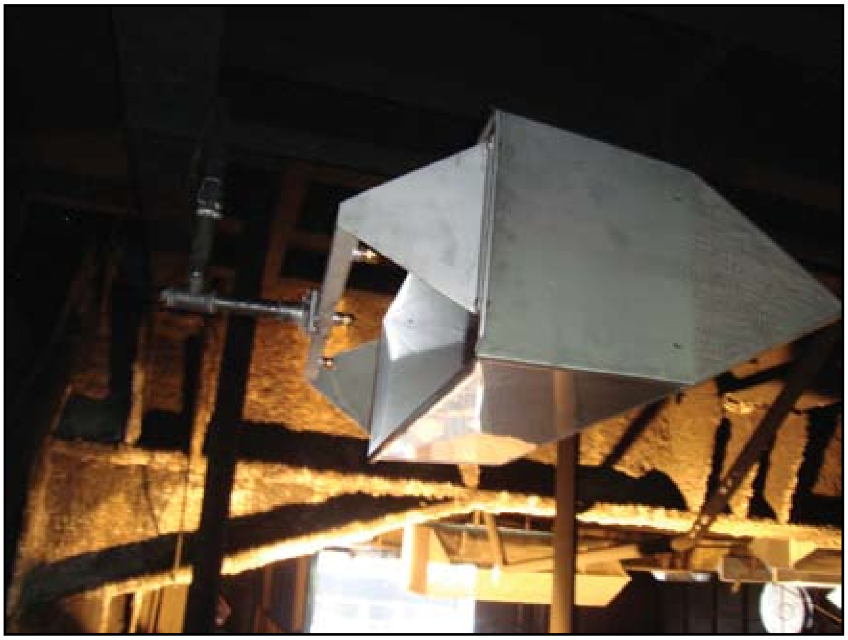

FIGURE 1
HotFoam HG-25 generator mounted in the overhead grid system.

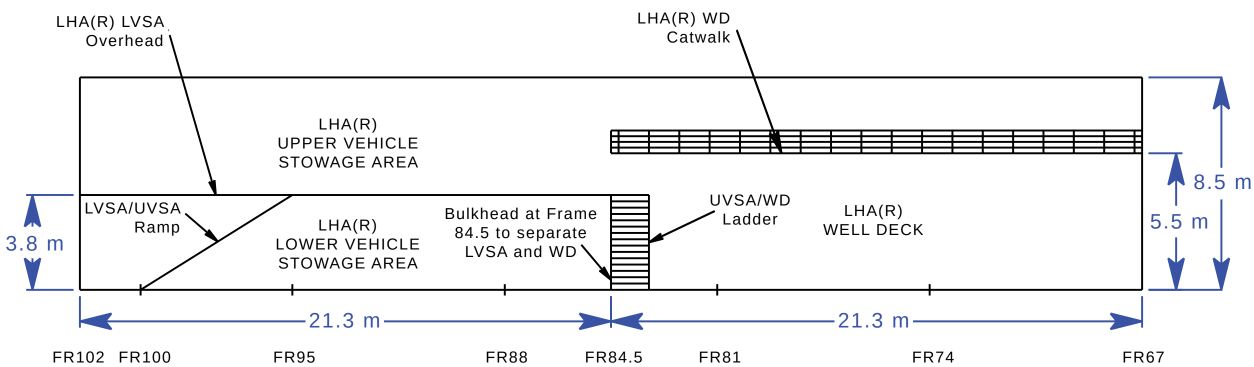

FIGURE 2
Ex-USS *Shadwell* test area, section view.

A quadruple fire threat consisting of Class A and B test materials was developed to simulate an actual fire casualty (Fig. 3). The Class A fuel package, which provided a repeatable fire test surrogate for Class A vehicle fires, consisted of six 1.8-m (6-ft) high stacks consisting of 15 standard size oak pallets. This Class A fuel package created a 30 megawatt (MW) fire when all were fully involved. The two Class B (marine diesel) spill fire scenarios included a two-dimensional pool fire in a test pan measuring 4.6 m by 6.1 m (15 ft by 20 ft) and a three-dimensional running fuel fire using a 0.9-m (3.0-ft) by 0.6-m (2-ft) by 1.8-m (6-ft) high steel structure metered to flow fuel at a rate of 13.6 Lpm (3.6 gpm). The calculated heat release rates for these two Class B fire threats were 60 MW and 8 MW, respectively. An additional, shielded Class B-initiated small wood crib was located in an adjacent compartment that opened into the Well Deck test area. This setup simulated a vehicle in the Well Deck that had an obstructed area such as an open vehicle door, tailgate, or window. Figure 4 provides a picture of the developed quadruple fire threat prior to fire suppression system activation.

Five full-scale tests were conducted to assess the efficacy of the inside air-generated high expansion foam system. The fire test scenarios were developed and selected to enable a direct comparison to previously conducted AFFF and outside air high expansion foam fire test findings.[3,4] The determined tests can be categorized as follows:

1. Cold Discharge test. This test was conducted to establish and verify the system pressure flow, concentration characteristics, and submergence (fill)/dissipation times.

2. Fire test with the Class B pool, Class A pallets, and Class A adjacent space fire, but without the Class B cascade running fuel fire.
3. Fire tests that included the "3D" cascade running fuel fire in addition to the other fire threats. This was the "quadruple" 98 MW fire test scenario.

All tests were conducted with the after-test area door partially open, resulting in a vent opening of approximately 27 m^2 (286 ft^2) in the test area. Measures of fire control and extinguishment were derived by visual observation and by thermocouple data.

RESULTS

The following definitions were used to conduct the tests and analyze the data:

1. Pre-burn Time – the time from ignition of the Class B pool or cascade running fuel fire.
2. Knockdown – the time when very rapid cooling occurred within the pallets.
3. Extinguishment – the time when:
   a. By visual or video observation, no flaming combustion was observed; or
   b. By data, the time at which the last thermocouple reached 230 °C (446 °F) for Class A fires (i.e., approximately the piloted ignition temperature of wood or paper) or approximately 50 °C (122 °F) above the pool or cascade (i.e., below the flash point of marine diesel).
4. Submergence (fill) Time – the time from system activation to the time for foam to reach various heights in the Well Deck.
5. Foam Dissipation (breakdown) Time – the time the system was secured until the foam drained to reach a certain level in the Well Deck.

The cold discharge test was conducted with 23 overhead HotFoam generators. The adjacent compartment was open to the Well Deck volume, making the total floodable volume 1173 m^3 (41,328 ft^3). The temperature in the space was 31 to 32 °C (87.8 to 89.6 °F). The foam filled the desired volume within the Well Deck test area in 1 minute 44 seconds, which was in good agreement with the pre-test calculation of 1 minute 30 seconds (Fig. 5). The calculated average fill rate was 2.2 m/minute (7.2 ft/minute) and the calculated expansion ratio was 375:1. After holding the foam for a period of 60 minutes, the overhead generator system was again activated with water only to note its potential foam knockdown capability, which could be used for future high expansion foam firefighting doctrine development. It was observed that this tactic was able to dissipate the foam blanket to within 0.6 to 0.9 m (2 to 3 ft) of the deck in 120 seconds, which would enable adequate access for post-fire investigation activities and a reasonably quick unmanned process for space reclamation efforts following a shipboard fire event.

The first fire test included the Class B pool, Class A pallet, and the Class A adjacent space fire threats. After activating the HotFoam system, there was rapid extinguishment of the pool fire (36 seconds) and pallet fires (76 seconds). The adjacent space fire was extinguished in 2 minutes 12 seconds. The time to fill the Well Deck test area to the desired level was 4 minutes 38 seconds. Fluctuations in oxygen concentration measured low in the space, and the total heat flux measured approximately 6 m (20 ft) away from the test pan area indicated some level of steam production effects during the fire suppression process.

The next three fire tests included the Class B cascade running fuel fire in addition to the other fire threats and a delayed activation time to further challenge the foam generation process using inside air within a post-flashover thermal layer environment. For fire test two, extinguishment of the Class B pool fire occurred at 43 seconds, the Class A pallets at 90 seconds, the Class B cascade at 96 seconds, and the Class A adjacent space fire at 10 minutes 16 seconds. The time to fill the Well Deck to the desired level was 10 minutes 12 seconds. It was apparent that the increase in heat load affected the build-up of foam and there was also a notable increase in steam production.

For fire tests 3 and 4, the solution flow rate and configuration/location of the foam generators were adjusted to further investigate the potential impact these changes may have on inside air-generated foam expansion. In fire test 3, 18 generators were kept in the overhead and 12 generators were located approximately mid-level in the Well Deck compartment to lessen their exposure to the upper hot thermal layer. In this arrangement, the HotFoam system extinguished the Class B pool in 12 seconds, the Class A pallet fires in 36 seconds, the Class B cascade running fuel fire in 36 seconds, and the Class A adjacent space fire in 4 minutes 42 seconds. The time to fill the Well Deck to the desired level was 5 minutes 45 seconds. Foam expansion improved and steam production was notably less in comparison to fire test 2. For fire test 4, 30 generators were located in the overhead, resulting in the Class B pool fire extinguishment in 36 seconds, the Class A pallet fires in 48 seconds, the Class B cascade running fuel fire in 66 seconds, and the Class A adjacent space fire in 2 minutes 6 seconds. The HotFoam system was secured at about 2 minutes of activation due to a ruptured pipe casualty to the system. Although all fires were quickly extinguished, there was very little visible foam on the deck (Fig. 6). This indicates that all extinguishment action was done either by water

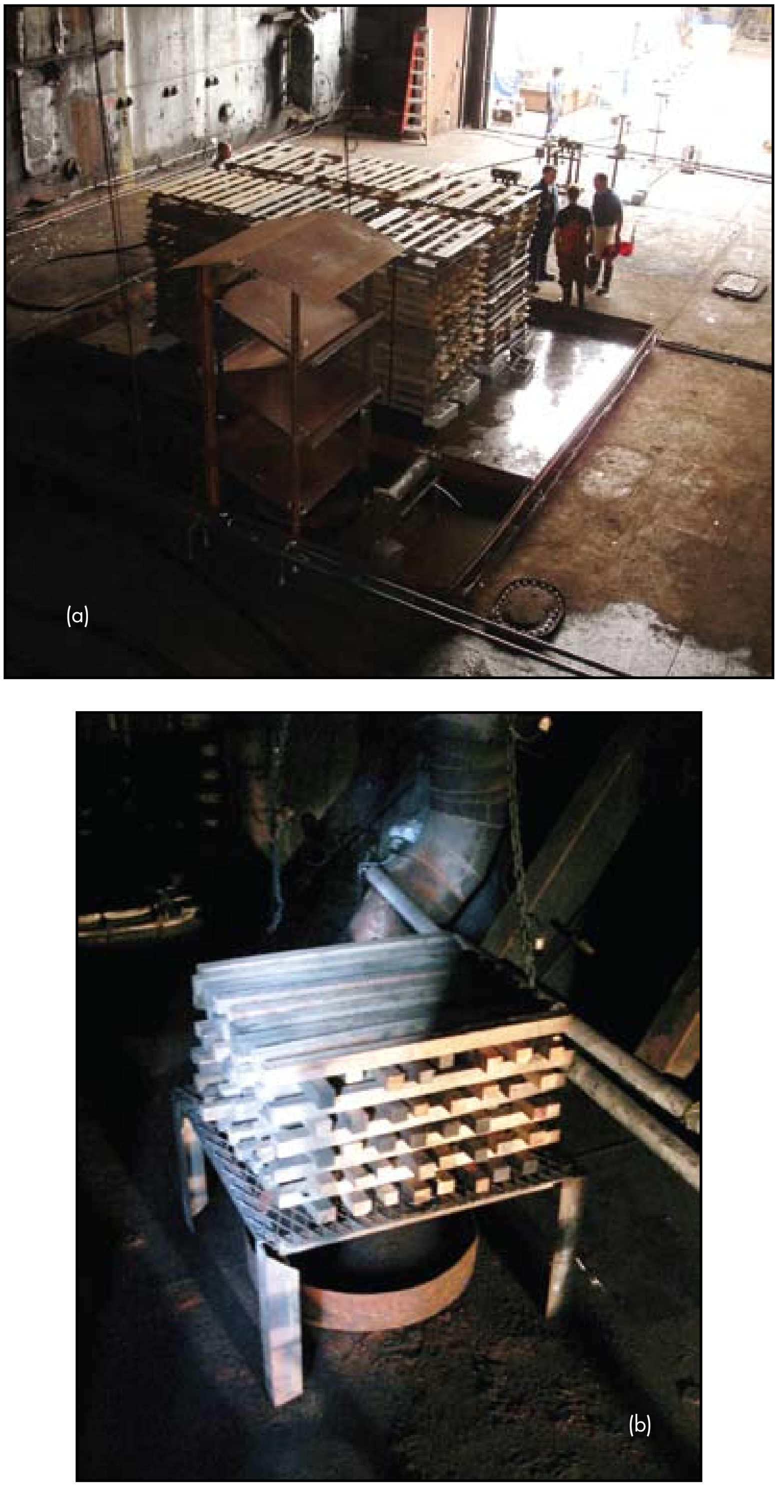

FIGURE 3
(a) Well Deck Mixed Class A and Class B Fuel Package. (b) Class A fuel package for the adjacent space fire.

FIGURE 4
Quadruple 98 MW test fire prior to HotFoam activation.

FIGURE 5
HotFoam cold discharge test.

cooling or steam smothering. Water conversion to steam and localized oxygen depletion is postulated as the primary mechanism of suppression as opposed to direct surface wetting. The suppression of the Class B cascade and adjacent space Class A fires (where there was no direct water application) supports this theory.

SUMMARY AND CONCLUSIONS

There was concern that the HotFoam system would be ineffective on large fires due to injection of heat and smoke into the generators. This might prevent generators located inside the affected space from generating good quality foam. The system tested was effective on all fire scenarios, including the quadruple fire threat and delayed activation scenarios. The HotFoam system, at lower comparable solution flow rates, 2040 to 2600 Lpm (538–684 gpm), was as effective or more effective than the previously tested outside air-generated high expansion foam flowing at 3100 Lpm (820 gpm). The outside air high expansion foam appears to have relied more on cooling and fuel surface oxygen displacement. The HotFoam system, particularly for the high heat threat, delayed activation scenario, relied on steam conversion and associated steam smothering. Although the steam generation phenomenon associated with the HotFoam system was an unforeseen finding that requires further study, it did provide important insight into some additional capabilities that a HotFoam system may possess. This noted steam generation phenomenon may also open up other avenues of opportunity for developing an alternative overhead AFFF nozzle design that is better suited to combating mixed Class A and Class B fire threats. These additional fire suppression research efforts will help to ensure that future ship classes with large volume mission critical spaces are adequately protected against any fire threat that may be present.

[Sponsored by NAVSEA 05P14]

REFERENCES

[1] A.C. Lures, M.A. Harrison, H.V. Pham, J.A. Lynch, J.L. Scheffey, J.P. Farley, F.W. Williams, and M.P. Hunstad, "Test Report for Well Deck and Vehicle Stowage Area Vulnerability and Fire Model Validation Tests, Series 1 – An Evaluation of Aqueous Film Foaming Foam (AFFF) Suppression Systems for Protection of LHA(R) Well Deck and Vehicle Stowage Areas," NRL Ltr Rpt 6180/0369, Naval Research Laboratory, Washington, DC, October 26, 2004.

[2] I. Wilder, "High Expansion Foam for Shipboard Fire Fighting," Naval Applied Science Laboratory, 72nd Annual Meeting of the National Fire Protection Association, Atlanta GA, May 20, 1968.

[3] J.L. Scheffey, J.P. Farley, and F.W. Williams, "Summary Report – AFFF Overhead Sprinkler Suppression Systems Used to Combat a Hangar Bay, Well Deck, or Vehicle Storage Fire Threat," NRL Ltr Rpt 6180/0171, Naval Research Laboratory, Washington, DC, July 23, 2008.

[4] J.L. Scheffey, J.P. Farley, H.V. Pham, and F.W. Williams, "Summary Report – High Expansion Foam Suppression Systems Used to Combat a Hangar Bay, Well Deck, or Vehicle Storage Fire Threat," NRL Ltr Rpt 6180/0196, Naval Research Laboratory, Washington, DC, September 22, 2008.

FIGURE 6
Fire test 4, immediately after fire suppression due to steam smothering.

THE AUTHORS

FREDERICK W. WILLIAMS is Director of the Navy Technology Center for Safety and Survivability at the Naval Research Laboratory, Washington, DC. He is also Technical Director of the ex-USS *Shadwell* (LSD-15), the Navy's full-scale damage control fire fighting research ship based in Mobile, Alabama. Dr. Williams has authored or co-authored over 800 technical papers and reports. He is the recipient of the Naval Research Laboratory's E.O. Hulbert Scientific Achievement Award and the Equal Employment Opportunity (EEO) Award. In addition, he has received three Alan Berman publication awards, the Navy's Meritorious Civilian Service Award, and the Navy's Superior Service Award, and was named Fire Protection Man of the Year by the Society of Fire Protection Engineers. Dr Williams is also the recipient of the 2003 Royal Institution of Naval Architects – Lloyd's Register Safer Ship Award and the 2004 Harry C. Bigglestone Award for Excellence in Communication of Fire Protection Concepts, awarded by the National Fire Protection Research Foundation. Most recently, the Office of Naval Research has awarded him the Bisson Prize for his pioneering work in shipboard damage control automation that has transitioned to the newest Navy classes of ships including the Littoral Combat Ship (LCS) in Mobile, AL. Dr. Williams received his Ph.D. in chemistry from the University of Alabama. He was a National Research Council Postdoctoral Fellow at NRL from 1965 to 1966.

JOHN P. FARLEY earned his B.S. degree from Lowell Technological Institute in mathematics in 1974 and his M.A. degree from the University of Rhode Island in marine affairs in 1981. Prior to joining NRL, he served as a surface line officer, which included shipboard assignments on the USS *Vesole* (DD-878), USS *Okinawa* (LPH-3), USS *Jesse L. Brown* (FF-1089), USS *Josephus Daniels* (CG-27), and the USS *Connole* (FF-1056). He joined the Navy Technology Center for Safety and Survivability of the Naval Research Laboratory's Chemistry Division in 1994, where he has worked as the Project Officer for the Navy's fire test ship ex-USS *Shadwell* developing new fire protection technologies and firefighting doctrine for the naval surface and submarine forces. While assigned to NRL, he has been awarded the Legion of Merit for exceptional meritorious service in 1997, two Alan Berman Research Publication awards for 1997 and 2004, and the 2003 Royal Institution of Naval Architects – Lloyd's Register Safer Ship Award.